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Bose-Einstein correlations of direct photons in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV

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The current status of the analysis of direct photon Bose-Einstein correlations in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV done by the PHENIX collaboration is summarized. All possible sources of distortion of the two-photon correlation function are discussed and methods to control them in the PHENIX experiment are presented.

1. Introduction

Photons have an extremely long mean free path length and escape from the hot matter without rescattering. By measuring their Bose-Einstein (or Hanbury-Brown Twiss, HBT) correlations one can extract the space-time dimensions of the hottest central part of the collision[1,2,3,4,5] in contrast to hadron HBT correlations which measure the size of the system at the moment of its freeze-out. Moreover, photons emitted at different stages of the collision dominate in different ranges of transverse momentum[6], therefore measuring photon correlation radii at various average transverse momenta (K_T) one can scan the space-time dimensions of the system at various times and thus trace the evolution of the hot matter.

Photons emitted directly by the hot matter – direct photons – constitute only a small fraction of the total photon yield while the dominant contribution comes from decays of the final state hadrons, mainly $\pi^0 \to 2\gamma$ and $\eta \to 2\gamma$ mesons. Fortunately, the lifetime of these hadrons is extremely large and the width of the Bose-Einstein correlations between the decay photons is of the order of a few eV and cannot obscure the direct photon correlations. This feature can be used to extract the direct photon yield[3]: assuming that direct photons are emitted incoherently, the photon correlation strength parameter can be related to the proportion of direct photons as $\lambda = 1/2(N_\gamma^{dir}/N_\gamma^{incl})^2$. This approach is probably the only way to experimentally measure direct photon yield at very small p_T. Presently, the only experiment to

*For the full list of the PHENIX collaboration and acknowledgments, see[9].

have measured direct photon Bose-Einstein correlations in ultrarelativistic heavy ion collisions is WA98[7]. An invariant correlation radius was extracted and the direct photon yield was measured in Pb+Pb collisions at $\sqrt{s_{NN}} = 17$ GeV.

Since the strength of the direct photon Bose-Einstein correlation is typically a few tenths of a percent, it is important to exclude all background contributions which could distort the photon correlation function. These contributions can be classified as following: apparatus effects (close clusters interference – attraction of close clusters in the calorimeter during reconstruction) and correlations caused by real particles. The latter in turn can be divided into contribution due to "splitting" of particles – processes like antineutron annihilation in the calorimeter and photon conversion on detector material in front of the calorimeter; contamination by correlated hadrons (e.g. Bose-Einstein-correlated $\pi^{\pm}$); background correlations of decay photons. In this paper we consider all of these contributions in detail and describe how to control for them in the PHENIX experiment.

2. Analysis

This analysis is based on the data taken by PHENIX in Run3 (d+Au) and Run4 (Au+Au). The total collected statistics is ≈ 3 billion d+Au events and ≈ 900 M Au+Au events. Details of the PHENIX configuration in these runs can be found in references [8] and [9], respectively.

2.1. *Apparatus effects*

Since correlation functions are rapidly rising functions at small relative momenta any small distortion of the relative momentum for real pairs, because of errors in reconstruction of close clusters in the calorimeter ("cluster attraction") for example, can lead to the appearance of a fake bump in the correlation function.

To explore the influence of cluster interference in the calorimeter EMCAL, we construct a set of correlation functions by applying different cuts on the minimal distance between photon clusters in EMCAL. To quantify the difference between these correlation functions we fit them with a Gaussian and compare the extracted correlation parameters. We find that for correlation functions that include clusters with small relative distances there is strong dependence on minimal distance cut, but for distance cuts above 24 cm (4-5 modules) the correlation parameters are independent of the relative distance cut. This implies that with this distance cut the apparatus effects are sufficiently small.

2.2. *Photon conversion, $\bar{n}$ annihilation, and similar backgrounds*

The next class of possible backgrounds are processes in which one real particle produces several clusters in the calorimeter close to each other. These are processes like $\bar{n}$ annihilation in the calorimeter producing several separated clusters, or photon conversion in front of calorimeter, or residual correlations between photons that

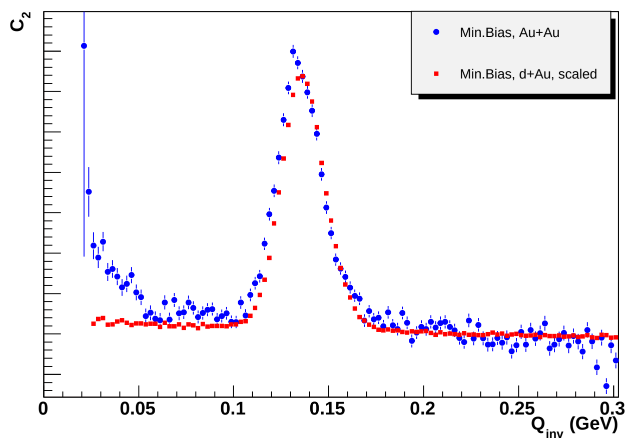

Fig. 1. Two-photon correlation function measured in d+Au collisions at $\sqrt{s_{NN}} = 200$ GeV scaled to reproduce the height of the π^0 peak in Au+Au collisions compared to the same correlation function measured in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV. Absolute vertical scale is omitted in this technical plot.

belong to different π^0 in decays like $\eta \to 3\pi^0 \to 6\gamma$. The common feature of this type of process is that their strength is proportional to the number of particles per event and not to the square of the number of particles, as would be the case for Bose-Einstein correlations.

To estimate the upper limit on these contributions, we compare two-photon correlation functions, calculated in d+Au and Au+Au collisions. For the moment we assume, that all correlations at small relative momenta seen in d+Au collisions are due to the background effects under consideration. Then we scale the correlation function obtained in d+Au collisions with the number of π^0 (that is we reproduce the height of the π^0 peak in Au+Au collisions):

$$C_2^{scaled} = 1 - \frac{h_\pi^{Au+Au}}{h_\pi^{d+Au}}(C_2 - 1). \tag{1}$$

The result of this operation is shown in Fig. 1. We find that the scaled d+Au correlation function lies well below (close to unity) the correlation function calculated for Au+Au collisions at small relative momenta. From this we conclude that the contribution from effects with strength proportional to the first power of the number of particles is negligible in Au+Au collisions.

2.3. *Charged and neutral hadron contamination*

Another possible source of distortion of the photon correlation function is a contamination by (correlated) hadrons. Although we use rather strict identification criteria

for photons there still may be some admixture of correlated hadrons contributing to the region of small relative momenta.

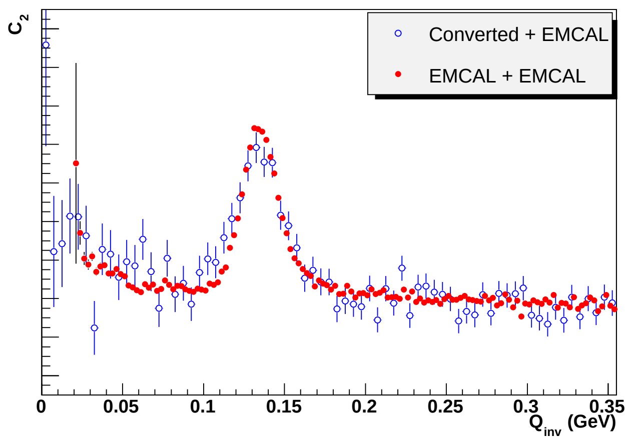

Fig. 2. Comparison of two-photon correlation functions measured in Au+Au collisions at $\sqrt{s_{NN}} =$ 200 GeV by two different methods: both photons are registered in the EMCAL (closed) and one photon is registered in EMCAL while the other is reconstructed through its external conversion (open). Absolute vertical scale is omitted in this technical plot.

To exclude this possibility, we construct the two-photon correlation function using one photon registered in the calorimeter EMCAL and reconstructing the second photon from its conversion into an e^+e^- pair on the material of the beam pipe. The photon sample, constructed using external conversions is completely free from hadron contamination, so comparison of the standard correlation function with the pure one allows to estimate the contribution from non-photon contamination. This comparison is shown in Fig. 2. We find that the correlation function constructed with the more pure photon sample demonstrates a slightly larger correlation strength. This demonstrates that the observed correlation is indeed a photon correlation, while hadron contamination in the photon sample just increases combinatorial background and reduces the correlation strength. In addition, this comparison shows that we have properly excluded the region of cluster interference. Due to deflection by the magnetic field the electrons of the e^+e^- conversion pair hit the calorimeter far from the location of the pair photon used in the correlation function and thus effects related to the interference of close clusters are absent.

2.4. *Photon residual correlations*

The last possible source of the distortion of the photon correlation function are residual correlations between photons. We have already demonstrated that the con-

tributions of residual correlations between photons in decays like $\eta \to 3\pi^0 \to 6\gamma$, with strength proportional to N_{part} and not N_{part}^2 is negligible in Au+Au collisions. Below we consider other effects, which may cause photon correlations. These are collective flow (and jet-like correlations) and correlations between photons, originated from decays of Bose-Einstein correlated mesons. Collective (elliptic) flow as well as jet-like correlations are long-range effects, resulting in correlations at relative angles much larger than under consideration here (for example, the opening angle of a photon pair with 20 MeV mass and $K_T = 500$ MeV is ~ 5 degrees). Monte-Carlo simulations demonstrate that flow and jet-like contribution are indeed negligible.

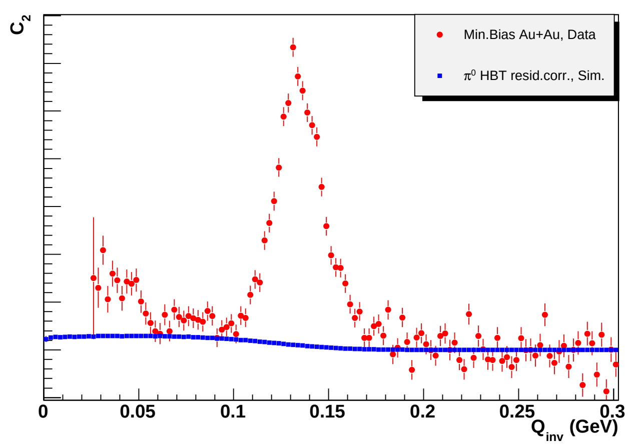

Fig. 3. Comparison of two-photon correlation functions measured in Au+Au collisions at $\sqrt{s_{NN}} =$ 200 GeV with Monte-Carlo simulations of the contribution of residual correlations due to decays of Bose-Einstein-correlated neutral pions. Absolute vertical scale is omitted in this technical plot.

Potentially, the most serious distortion of the photon correlation function are residual correlations between decay photons of HBT-correlated π^0s. Monte-Carlo simulations show that this contribution is not negligible, but has a rather specific shape (see Fig. 3), so that it does not distort the photon correlation function at small Q_{inv}. This result can be explained as follows. Let us consider two π^0s with zero relative momentum. The distribution of decay photons is isotropic in their rest frame, and the probability to find a collinear photon pair ($Q_{inv} = 0$) is suppressed due to phase space reasons. The photon pair mass distribution has a maximum at $2/3\, m_\pi$, not at zero. After convoluting with the pion correlation function we find a step-like two-photon correlation function[3]. On the other hand, if one artificially chooses photons with momentum along the direction of the parent π^0 (e.g. by looking at photon pairs at very large K_T), then the shape of the decay photon correlation function will reproduce the shape of the parent π^0 correlation. This

probably explains the different shape of the residual correlations due to decays of HBT-correlated π^0 found in[10].

3. Conclusions

We have presented the current status of analysis of direct photon Bose-Einstein correlations in the PHENIX experiment. We are able to measure the two-photon correlation function with a precision sufficient to extract the direct photon correlations. Correlation measurements in which one of the photon pair has converted to an e^+e^- pair have been used to provide an important cross-check. We have demonstrated that all known backgrounds are under control. The extraction of the correlation parameters of direct photon pairs is in progress.

References

1. A.N. Makhlin, *JETP Lett.* **46**:55 (1987); A.N. Makhlin, *Sov.J.Nucl.Phys.* **49**:151,(1989).
2. D.K. Srivastava, J. Kapusta, *Phys.Rev.* **C48**:1335 (1993); D.K. Srivastava, C. Gale, *Phys.Lett.* **B319**:407 (1993); D.K. Srivastava, *Phys.Rev.* **D49**:4523 (1994); D.K. Srivastava, J. Kapusta, *Phys.Rev.* **C50**:505 (1994). D.K. Srivastava, *Phys.Rev.* **C71**:034905 (2005); S. Bass, B. Muller, D.K. Srivastava, *Phys.Rev. Lett.* **93**:162301 (2004).
3. D. Peressounko, *Phys.Rev.* **C67**:014905 (2003).
4. J. Alam et al., *Phys.Rev.* **C67**:054902 (2003); J. Alam et al., *Phys.Rev.* **C70**:054901 (2004).
5. T. Renk, *Phys.Rev.* **C71**:064905 (2005); hep-ph/0408218.
6. D. d'Enterria and D.Peressounko, *Eur.Phys.J.***C46**:451 (2006).
7. M.M. Aggarwal et al., *Phys.Rev.Lett.* **93**:022301 (2004).
8. S.S.Adler et al., (PHENIX collaboration), Phys.Rev.Lett. **98**:012002.
9. S.Bathe et al., (PHENIX collaboration), Nucl.Phys. **A774**:731 (2006).
10. D.Das et al., nucl-ex/0511055.